Improving Design of SCR Systems with CFD Modeling

Bradley Adams
Reaction Engineering International, 77 West 200 South, Suite 210, Salt Lake City, UT 84101
E-mail: adams@reaction-eng.com; Telephone: (801) 364-6925 x18; Fax: (801) 364-6977

Connie Senior
Reaction Engineering International, 77 West 200 South, Suite 210, Salt Lake City, UT 84101
E-mail: senior@reaction-eng.com; Telephone: (801) 364-6925 x37; Fax: (801) 364-6977

Summary

Recent utility experience has shown that selective catalytic reduction (SCR) technology can provide significant NOx reduction for utility boilers, but has also shown that retrofitting large systems at existing power plants can prove challenging. Design of SCR systems is dependent on a number of factors, including cost, plant layout, operating conditions, and performance requirements. The complexity of these factors makes the design process challenging. To remain competitive, SCR designers must utilize the best experience, design methodologies and analytical/engineering tools available to bid and complete projects. One relatively new tool available to aid SCR designers, both before and after system installation, is computational fluid dynamics (CFD). CFD modeling can provide several advantages to system designers. When correctly utilized, modeling can provide an improved understanding of flue gas flow patterns, gas velocities, pressure drop, temperature and species concentration profiles, ammonia mixing patterns, and NOx reduction in SCR ductwork and reactors. This allows designers to understand the impacts of different duct designs, ammonia injection grid designs, and catalyst designs on SCR performance before a system is installed.

This presentation describes an SCR project at a 550 MW coal-fired boiler where CFD modeling was used to evaluate flue gas conditions entering the ammonia injection grid (AIG) and SCR catalyst, to improve design of the AIG including biasing ammonia flows for improved NOx reduction, to quantify system pressure drop, and to evaluate SCR NOx reduction and ammonia slip for different flue gas conditions and ammonia profiles. Predicted results were subsequently compared with measurements from the installed system.

Three-dimensional CFD flow modeling was conducted in combination with a one-dimensional SCR chemistry model to simulate the parallel SCR systems at the plant. The models were used to calculate flue gas flow patterns and velocity profiles, overall pressure drop through duct work, duct heat transfer, temperature distribution, NH_3 distribution from the AIG, and NO reduction through SCR catalyst. Modeling of the SCR ductwork and reactor was divided into three components: 1) a three-dimensional CFD duct flow model used to calculate flue gas properties through the ductwork before and after the SCR reactor, 2) a three-dimensional CFD model of the AIG that used a highly refined grid to calculate the ammonia injection and mixing in the AIG zone, 3) a one-dimensional SCR catalyst submodel used to calculate the NH_3 and NO reactions across the SCR catalyst.

The three dimensional CFD models calculated the velocity profiles, pressure drop, temperature profiles, NH_3 injection and mixing, and species concentration profiles based on the system geometry and incoming flue gas properties. The flow, temperature and species concentration profiles entering the SCR catalyst were geometrically divided into groups representing inlet conditions for different sections of the catalyst. NOx and NH_3 concentrations at the SCR inlet and exit were averaged to determine the catalyst performance. NOx chemistry across the SCR catalyst was calculated using a one-dimensional catalyst submodel that accounts for catalyst performance as a function of catalyst design, temperature, NOx concentration, NH_3 concentration, flue gas composition, and residence time.

CFD predictions showed regions of high and low velocities based on the geometry of the SCR ducts. Velocity profiles can be useful in identifying regions of poor flow distribution and nonuniform velocities. These results can suggest where improvements to guide vane designs can be made (if needed). In general, the turning vanes or guide vanes specified in the initial design were found to be effective in maintaining flow uniformity after duct turns, contractions and expansions.

Predicted pressure drops in both SCR units were consistent with measured data (i.e., within 10%) and all trends due to flow velocities and geometry designs were accurately predicted. Unit B was predicted to have a lower pressure drop than Unit A at both MCR and low loads due to the longer duct lengths (higher flow resistance) in Unit A. These same trends could be seen in the measured data, although the measured data is further biased by the differences in flue gas flow rates between the units. The largest pressure drop in both units was across the catalyst, which accounted for roughly half of the total pressure drop in each system.

As expected, NO profiles were found to correlate strongly with NH_3 distribution. High regions of NH_3 resulted in lower NO and vice versa. NO reduction and ammonia slip were found to be functions of both NH_3/NO ratio and residence time in the catalyst. At MCR, the average NH_3/NO ratio of 0.814 resulted in a NO reduction of 79.6% and an ammonia slip of 4 ppm NH_3 @ 6% O_2, dry (from a baseline NOx level of 210 ppm). A similar ratio at low load resulted in NO reduction 81.4% (the theoretical maximum) with 0 ppm slip. Results for both units were very similar. At MCR there was not sufficient residence time in the catalyst to completely react all of the NH_3 and NO; this resulted in NH_3 slip. In the low load cases, both conditions for optimal performance were met: (1) NH_3 was distributed well enough to provide sufficient reagent along the NO profile entering the catalyst (NH_3/NO profile sufficiently uniform), (2) residence time in catalyst was long enough for nitrogen chemistry to react completely.

Modeling results (and measurements) indicated a bias in the flue gas velocity profile in the AIG region. For fully open AIG injector nozzles, this leads to NH_3 biases (nonuniform profiles) at the catalyst inlet. CFD modeling was used to simulate the effect of AIG tuning, however, the improved uniformity did not reduce the average NO at the reactor outlet (43 ppm versus 42.5 ppm). The one-dimensional catalyst submodel was also used to conduct a series of sensitivity studies to look at the impacts of NH_3/NO ratio entering the catalyst and the flue gas residence time in the catalyst.